

## MICROSTRUCTURE, MECHANICAL PROPERTIES AND SLIDING WEAR BEHAVIOUR OF SILICON CARBIDE REINFORCED AL 6026 COMPOSITES

H. M. SOMASHEKAR<sup>1</sup>, GOWTHAMA. K<sup>2</sup> & B. SURESHA<sup>3</sup>

<sup>1,2</sup>Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India

<sup>3</sup>Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, India

### ABSTRACT

*In this research work, the role of fine silicon carbide (SiC) particles on mechanical properties and dry sliding wear behaviour of Al 6026 composites were investigated. Al 6026 matrix reinforced with different weight percentages (3, 5, 7, and 10) of SiC particles have been fabricated following liquid metallurgy route. Microstructure, hardness, and tensile properties of these composites were evaluated and compared with Al 6026. In addition, dry sliding wear behaviour of Al 6026 based composites were conducted using pin-on-plate wear test rig. Worn-out coupons of the selected composites were analyzed using scanning electron microscope for predicting the involved wear mechanisms. The major findings are: i) Al 6026 composites showed improved hardness, tensile strength and Young's modulus, ii) tensile properties of Al 6026/10% SiC composites were lower than Al 6026/7% SiC indicating that the critical weight fraction of SiC in Al 6026 is 7%, iii) specific wear rate of Al 6026 and SiC reinforced Al 2026 composites increases with increasing applied normal load and coefficient of friction decreases slightly at higher load, and iv) specific wear rate and friction coefficient of Al-SiC are lower than that of unreinforced Al 6026. These results reveals the effect of SiC reinforcement on improved mechanical properties, reduced friction coefficient, and better wear resistance of Al 6026 composites and provide a useful attendant for healthier control of their wear.*

**KEYWORDS:** Al 6026/SiC Composites, Microstructure, Tensile Properties, Wear & Worn Surface Topography

**Received:** Oct 15, 2019; **Accepted:** Nov 05, 2019; **Published:** Jan 02, 2020; **Paper Id.:** IJMPERDFEB202022

### INTRODUCTION

Metal matrix composites (MMCs), are principally metallic alloys strengthened with characteristically ceramic particulates. The most common matrix alloys engaged are aluminium (Al), magnesium and titanium. Al is the furthestmost exploited metal alloy as matrix in the growth of Al based composites and the elucidations for this have been described [1, 2]. The ultimate properties of Al based composites governed by the inherent properties of reinforcement selected and the type of Al alloy. Moreover, the processing method tailed for manufacturing of Al based composites also influence the final properties. This is because, most of the parameters put into deliberation during the design of Al based composites are allied with the ceramic particulates. Major parameter includes reinforcement type, size, shape, modulus of elasticity, hardness, distribution and interface between the reinforcement and matrix [2].

Aluminium amid some numerous metals is attractive due to its anticipated properties such as ductility, malleability, good conductivity, lightweight, functional strength and availability in abundance (8% of earth crust is Al). In conglomeration with sturdy materials like ceramic such as SiC, B<sub>4</sub>C, TiC, etc. are used to develop composites. The improved properties of the composites lead to finding a wide range of applications in industries

and structural applications (aerospace, automotive, marine, and military) [3–6].

The information on usage of ceramics are very limited, for instance, Laksmikanathan et al. [7] studied the addition of SiC (dual size) in Al-MMCs and showed an improvement in mechanical and wear resistance of the composites. Hayrettin et al. [8] studied the additions of combination of ceramics namely  $\text{Al}_2\text{O}_3$  and SiC (hybrid MMCs) in Al matrix and demonstrated improved hardness, compression strength and wear resistance of the Al matrix alloy. Yadav et al. [9] studied the addition of Al-SiC-CNT (multi walled) nano-hybrid composites and indicated an enhancement in mechanical strength and modulus as well as resistance to wear. Straffelini et al. [10] concluded that the Al hardness impacts the wear conduct of Al 6061- $\text{Al}_2\text{O}_3$  composites. How and Baker [11], in their investigation of wear conduct of Al 6061- saffil ( $\text{Al}_2\text{O}_3$ ) fiber and inferred that saffil is noteworthy in enlightening the wear resistance of the composites.

Vanarotti and Co-workers [12] studied the mechanical properties of SiC reinforced Al 356 composites manufactured by die-casting process. From the data generated, it was published that the hardness and tensile strength increased with increase in SiC loading. Though, their work does not provide information about the most optimum reinforcement in the Al alloy. Muthu Kumar et al. [13] studied the role of SiC in LM4 alloy processed via stir casting route. This work showed improvement in wear resistance as well as corrosion resistance. Liang and Co- workers [14] concluded that Al based SiC composites display superior wear resistance. Ramesh and Safiulla [14] contemplated wear of extruded Al 6061 reinforced with SiC,  $\text{Al}_2\text{O}_3$  and cerium oxide fortifications, and presumed that wear rates of extruded Al 6061/cerium oxide had superior wear resistance under similar test conditions. Ramesh et al. [16] stated that the higher loading of silicon nitride particles in Al 6061 has brought greater hardness and ultimate tensile strength.

From the above literature review, it is clear that there have been huge research studies on processing and properties evaluation of SiC and other ceramic particles reinforced MMCs, but an explicit understanding on the effect of very fine SiC particles ( $<30\text{ }\mu\text{m}$ ) reinforcement on improved wear resistance of Al-ceramic composites is still missing. In view of this, the present research work was aimed at synthesise of Al 6026/SiC composites containing various wt. % of SiC particulates and to study their microstructure, hardness, tensile properties, friction and wear behaviour. Furthermore, this research work gives a quantative understanding on the improved mechanical properties and superior wear resistance of Al-MMCs due to addition of very fine SiC as strengthening reinforcing material.

## MATERIALS AND METHODS

### Materials

Wrought Al 6026 alloy was used as matrix material and procured from Fefee Metallurgical, Bengaluru, India. The density of Al 6026 is  $2.72\text{ g cm}^{-3}$ , melting point of  $650^\circ\text{C}$ , Young's modulus and Poisson's ratio are 69 GPa and 0.34 respectively. The reinforcement chosen was SiC with average particle size of  $25\text{ }\mu\text{m}$ , supplied by M/s Carborundum Universal Limited, Kerala, India. The density of SiC is  $3.21\text{ g cm}^{-3}$ , melting point of  $2730^\circ\text{C}$ , Young's modulus and Poisson's ratio are 410 GPa and 0.14 respectively. Table 1 shows the chemical composition of Al 6026 [17].

**Table 1: Chemical Composition of Al 6026 Alloy**

Element	wt. %
Si	1.20
Fe	0.50
Cu	0.25
Mn	0.35
Mg	0.60
Cr	0.10
Zn	0.10
Bi	1.20
Ti	0.10
Others	0.15
Balance	95.45

### Fabrication of Composites

The fabrication of Al based composites were carried out by liquid metallurgy route via stir-casting process. Al ingots were placed in graphite crucible and heated to 800°C in the electrical furnace. Preheated SiC particles were brought into vortex of the liquid of Al, compounded after viable degassing with degasser namely hexachloroethane tablet. Mechanical stirring of the liquid metal for duration of 10 min was accomplished by utilizing artistic covered impeller made of steel. Spindle speed of 400 rpm and a pouring temperature of 800 °C were kept during stir casting process. The liquid metal was filled to the preheated molds made of cast iron. The cylindrical rods of diameter 30 mm, and length 200 mm cast composites of Al 6026/SiC were achieved. In addition, Al 6026 was also cast for comparison purpose. The designation of the Al matrix and Al 6026/SiC composites is given in table 2. The cast Al 6026 and Al 6026/SiC composites were machined to prepare the test coupons as per ASTM standards.

**Table 2: Designation of Al 6026 and its Composites**

Sl. No	Composites (Designation)	SiC (~25 µm) wt. %
1	Aluminium(Al 6026)	----
2	Aluminium + SiC(Al 6026/3SiC)	3
3	Aluminium + SiC(Al 6026/5SiC)	5
4	Aluminium + SiC(Al 6026/7SiC)	7
5	Aluminium + SiC(Al 6026/10SiC)	10

### Metallographic Examination

The coupons for microstructure study were prepared as per standard metallurgical procedures (IS: 7739 PART III - 1976 (RA 2007)), etched in etchant prepared using 90 ml water, 4 ml HF, 4 ml H<sub>2</sub>SO<sub>4</sub> and 2g CrO<sub>3</sub>. Carefully polished and mirror finished coupons were examined under Nikon-Upright metallurgical microscope (Make: Japan, Eclipse Ni-E) as shown in Figure 1 to obtain micrographs.



**Figure 1: Nikon Microscope.**

### **Hardness Measurement**

The hardness tests were accompanied as per ASTM-E10-18 Standards. Hardness tester (Brinell) was used having a ball indenter (diameter of 2.5 mm) and an applied load of 250 kg was used. The duration of load applied is 60 s. Twelve readings were taken for each coupon, at different positions to circumvent the conceivable effects of particle segregation.

### **Tensile Test**

The tensile tests were conducted in accordance with ASTM E8/E8M-13a standard at room temperature, using universal testing machine (UTM, 100 kN, Kalpak Instruments and Controls, Pune, India). The tensile test specimens of nominal diameter 12 mm and gauge length of 60 mm were machined from castings. Tensile properties such as yield strength, ultimate strength and percentage elongation were calculated. The presented results were based on the average of five coupons.

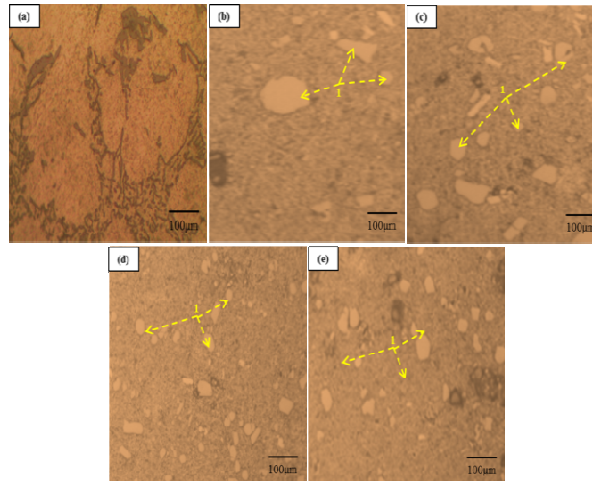
### **Wear Test**

Sliding wear tests were conducted at room temperature for constant sliding distance (450 m), sliding velocity ( $0.5 \text{ ms}^{-1}$ ) by varying the load as per ASTM G99-17. Wear tests were conducted using a computerized pin-on-plate apparatus (Make: Magnum Engineers, Bengaluru). The test coupons were of cylindrical pins (6 mm  $\phi$   $\times$  height 30 mm), while the plate was high carbon steel (EN 31) having hardness of 60 HRC. The surface roughness of the test pin and the disc were maintained at  $0.15 \mu\text{m Ra}$ . The term specific wear rate ( $K_s$ ) was used in the discussion of results.

## **RESULTS AND DISCUSSIONS**

### **Microstructure of Al 6026 and Al 6026/SiC Composites**

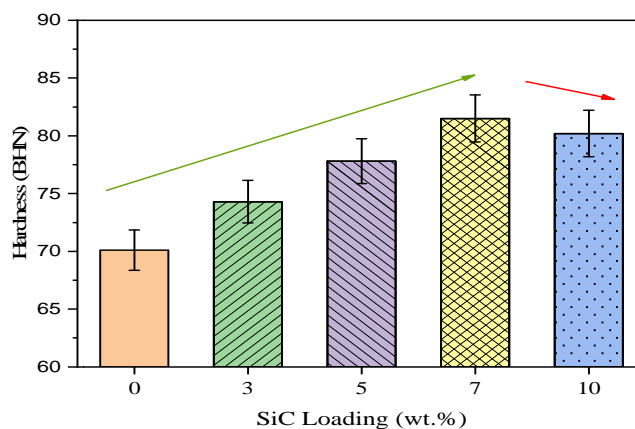
Figure 2 shows the optical micrographs of Al 6026 and Al 6026/SiC composites. Figure 2(a) shows the distribution of the primary dendrite alpha phase (Al rich) in Al 6026. Grey coloured wedge shaped SiC particles perceived in and around the inter dendrite sections ensued in augmented aspect ratio, marked by yellow colour arrows in Figures 2 (b-e). Also from Figures 2(b-e), it can be seen that the distribution of SiC particles in Al 6026matrix is almost uniform except at 10 wt. % SiC in Al 6026 (Figure 2(e)). After the examination of these micrographs, the SiC particles were found to be equitably distributed in the matrix without voids and discontinuities.



**Figure 2: Optical Micrographs of: (a) Al 6026, (b) Al 6026/3SiC (c) Al 6026/5SiC (d) Al 6026/7SiC (e) Al 6026/10SiC.**

### Hardness of Al 6026 and Al 6026/SiC Composites

From Figure 3, it is found that hardness (BHN) increases with increase in SiC loading in Al 6026 matrix material. As SiC loading is increased, the hardness gets increased up to certain weight percentage (7 wt. %) and then reduces slightly. As compared to as-cast Al 6026, 3, 5 and 7 wt. % SiC loadings show an increase in hardness of 6%, 11%, and 16% respectively in Al 6026/SiC composites.

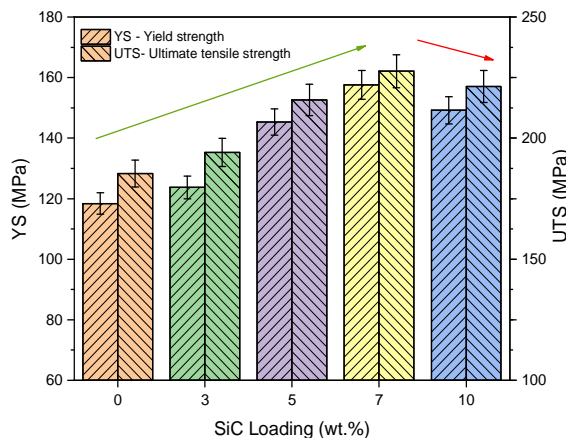


**Figure 3: Hardness of Al 6026 and Al 6026/SiC Composites.**

However, further increase in SiC loading from 7 to 10 wt. % decreased the hardness slightly as compared to Al 6026/7SiC composite. Optimum hardness of the composite was found for Al 6026/7SiC composite and further loading of SiC (10 wt. %) deteriorated the hardness of Al 6026, and this could be due to cluster of SiC particles in the Al matrix [18-21]. Saikereethi [22] concluded that the properties of Al based composites was controlled by ceramic particles. Moreover, the compacted interface holding load from the matrix material is stimulated to the strengthened material displaying improved hardness of the composites.

### Tensile Properties of Al 6026 and Al 6026/SiC Composites

In order to investigate the effect of SiC loading on the yield and ultimate tensile strengths as well as percentage elongation of Al 6026 and Al 6026/SiC composites, tensile testing has been carried out, and the results are plotted in figures 4, and 5.



**Figure 4: Yield Strength and Ultimate Tensile Strength of Al 6026 and Al 6026/SiC Composites.**

From figure 4, it can be perceived that the yield strength (YS) increases with increasing SiC loading except 10 wt. %. Also, the ultimate tensile strength (UTS) shows the similar tendency as YS. The increased tensile strength with increasing SiC loading may be related to inherent properties of the composite phases and interface between the reinforcement and matrix. The enhancement in the strength may be related to uniform dispersion of SiC particles, good interface between the Al 6026 and SiC reinforcement. In addition, the composite properties enhancement depends on the type of matrix material; reinforcement shape, size and interface between the constituent phases [23].

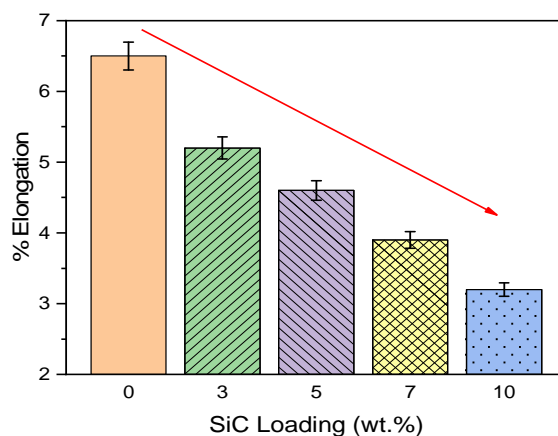
Tensile strength and Young's modulus of Al alloy are 185 MPa and 70 GPa respectively. However, for SiC, the values of tensile strength and Young's modulus are 226 MPa and 89 GPa. In terms of composite consisting of SiC and Al alloy, the composite properties can be calculated following the rule of mixtures (ROM) in the Halpin-Tsai equation [24]. Al-Jafaari [25] investigated the tensile properties of Al 7075/ $\text{Al}_2\text{O}_3$  nanocomposites. It was revealed that UTS and YS were profoundly improved by 8% and 7.2% respectively at 0.3 wt. %  $\text{Al}_2\text{O}_3$  loading. The higher strengths of nanocomposites could be credited to the way that  $\text{Al}_2\text{O}_3$  particles act as obstacles to the movement of dislocations.

The experimental data plotted in Figure 4 indicate that the YS and UTS increase with increasing SiC loading up to 7 wt. %. As compared to as-cast Al 6026, from Figure 4, it can be seen that for 3, 5 and 7 wt. % SiC accumulation showed an increase in YS by 5.3 MPa, 26.9 MPa, and 39.2 MPa, respectively. Further loading of SiC to 10 wt. % in Al 6026, the YS decreased by 8.4 MPa as compared to Al 6026/7SiC composites. In the present work, the improvement in casted composite coupons may be attributed to uniform distribution of SiC in Al 6026. Furthermore, SiC is very hard and acts as load bearing material in the matrix and improves the strength of the matrix material [7]. Overall, an improvement in YS of Al 6026/10SiC composite when compared to Al 6026 was found to be around 26%. As the reinforcement percentage is increased, the hardness gets increased up to certain weight percentage and then reduces slightly (Figure 3). Highest YS of the composite was found in Al 6026/7SiC and further increase in SiC loading (> 7 wt. %) deteriorated the YS and the same may be attributed to agglomeration of SiC particles in the Al 6026 [26].

Also, from Figure 4, it can be seen that UTS increases with increasing SiC loading in Al 6026. As compared to as-cast Al 6026, 3 wt. % SiC addition shows an increase of 8.7 MPa (4.7%), 5 wt. % SiC showed an increase of 30.4 MPa (16.4%), 7 wt. % SiC enhances by 42.2 MPa (22.8%), respectively. Further inclusion of 10 wt. % SiC showed decrease in UTS of 6.3 MPa (2.8%) as compared to Al 6026-7SiC composites. The optimum UTS is for Al 6026/7SiC composite and further addition of SiC to 10 wt. % reduced the UTS and this may be due to agglomeration of the reinforcement particles in



the matrix [26]. The improvement in as-cast Al 6026 with 7.5 wt. % SiC composites may be attributed to uniform distribution of reinforcement within Al 6026 (Figure 2(d)). Further, the SiC particles are very fine ( $\sim 25 \mu\text{m}$ ) and almost sharp edges were eliminated following ball milling process helped in improving the mechanical properties of Al 6026 alloy.

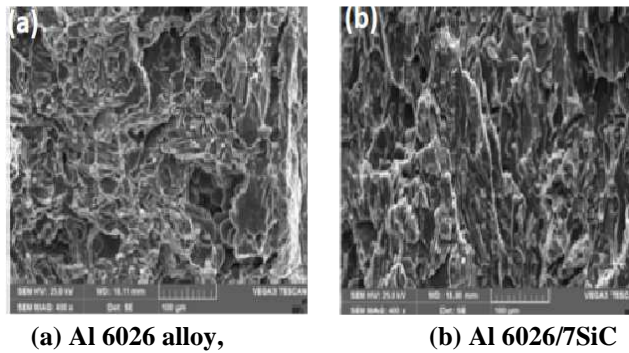


**Figure 5: Percentage Elongation of Al 6026 and Al 6026/SiC Composites.**

The elongation at break as a function of SiC loading is depicted in Figure 5. It may be seen from Figure 5 that the rate extension of Al 6026/SiC composites diminishes monotonically and impressively with the increase in SiC loading. The rate extension plummets by about 51% as the SiC loading is expanded from 0 to 10 wt. %. This abatement in rate lengthening in examination with the unreinforced Al 6026 is a most usually experienced inconvenience in particulate strengthened MMCs. The decrease in rate extension can be credited to the nearness of a hard SiC stage that is inclined to restricted split inception and expanded embrittlement impact because of neighbourhood stress fixation destinations at the SiC-Al 6026 framework interface. Henceforth, the presence of ceramic phase creates slip regions. Also, the fortifying particulates oppose the entry of separations either by making pressure fields in the framework or by instigating huge contrasts in the flexible conduct between the matrix and the scattered reinforcement [27].

#### **Fractographs of Tensile Test Failed Al 6026 and Al 6026/SiC Composites**

The tensile test coupons after failure were analyzed using SEM to study the fracture features. Figures 6(a) and (b) show fractographs of Al 6026 alloy and 7 wt. % SiC reinforced Al 6026 composites, respectively. From fractographs, the tensile test failed coupons (Figures 6(a) and (b)) it was observed that in Al 6026, fracture is overwhelmingly trans granular with minute voids (Figure 6(a)), their progressive growth, and final amalgamation around the removed debris. Breaking or crack of the coarse second-stage particles gave a general brittle appearance. Additional fracture features found are the presence of ductile tear ridges, few voids and ductile dimples. Analysis of fracture surface of Al 6026/7SiC composite confirms mixed ductile and brittle fracture. The fractured surface primarily exhibits trans granular tearing due to micro pore coalescence and cleavage facets. Referring Figure 4 presented in section 3.3, it is clear that the loads are transferred from the Al 6026 to the hard SiC particulates during tensile tests, thereby the SiC particles effectively reinforcing the Al 6026 alloy shown in figure 6(b).



(a) Al 6026 alloy, (b) Al 6026/7SiC  
Figure 6: SEM Fractographs of Composites.

This clearly indicates that the SiC-Al 6026 interface is strong enough due to the thorough wetting of SiC particulates. Furthermore, the convinced dislocations add to the strengthening of Al 6026/SiC composites. It is apparent that there is no debonding/pull-out of SiC particles from Al 6026 matrix material. SiC particles remain well bonded with Al-6026 matrix material. Also, tear ridges are found on the surface of the fracture coupon.

#### Wear Test Results of Al6026 Alloy and its Composites

The variation of specific wear rate ( $K_s$ ) of the Al 6026 and Al 6026/SiC composites at different loads can be seen in Figure 7. It clearly shows that the  $K_s$  increases with increase in applied normal load. It is obvious that the  $K_s$  is found to be minimum for composite containing 10 wt. % SiC at an applied load of 50 N. Thus, addition of SiC to Al 6026 is very efficient in reducing the  $K_s$ . The reduction in  $K_s$  may be ascribed to the increased hardness achieved due to uniform distribution and better interface between SiC and Al 6026.

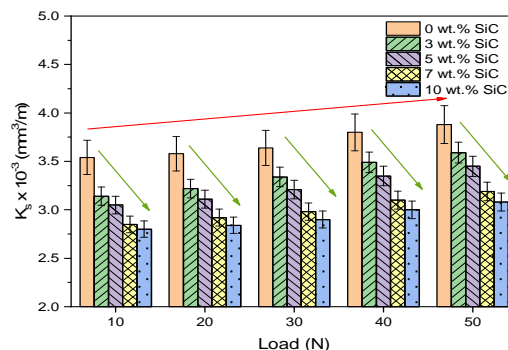


Figure 7: Specific Wear Rate as a Function of Load of Al 6026 and Al 6026/SiC Composites.

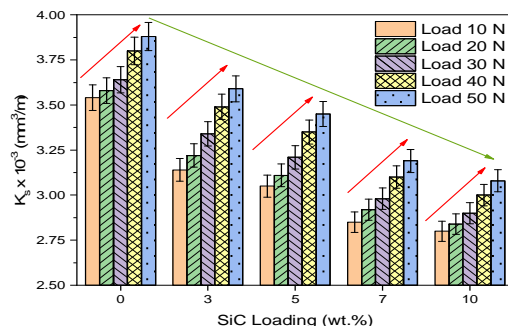


Figure 8: Specific Wear Rate as a Function of SiC Loading of Al 6026/SiC Composites.



From Figure 8, it can be seen that the  $K_s$  of Al 6026 coupons tends to decrease intensely with increased SiC loading at all loads applied. It is apparent from Figure 8 that the  $K_s$  of Al 6026/7SiC composite increases steadily with increasing applied normal load. Sorowordi et al. [28] confirmed that the  $K_s$  strongly dependent on the loading of ceramic reinforcement. The applied load affects the  $K_s$  of Al 6026 and Al 6026/SiC composites essentially, and is the most influential factor regulating the wear behaviour [29]. The  $K_s$  varies with the applied load, which is symptomatic of Archard's law, and is altogether lower in case of Al-based composites [30]. With increment in the applied load, there is greater  $K_s$  for Al 6026 and Al 6026/SiC composites. However, at all the applied loads selected, wear resistance of Al 6026/SiC composites are superior to the unreinforced Al 6026 alloy. The  $K_s$  is approximately 1.26 times lower than that of unreinforced Al 6026 alloy under the same test conditions. Thus, the unreinforced alloy suffers large  $K_s$  at high load. On the basis of the data as shown in figures 7 and 8, it is evident that the beneficial influences of the SiC loading increase with decreasing the applied normal load.

Steady state friction coefficient ( $\mu$ ) under different applied normal loads at 450 m and 0.5 m s<sup>-1</sup> are presented in Table 3. In general,  $\mu$  increases sharply at the beginning, reaching a peak at small sliding distances. It then decreases and attains a steady state value. This general behaviour is observed for both unreinforced Al 6026 and its composites.

**Table 3: Friction Coefficients of Al 6026 and Al 6026/SiC Composites**

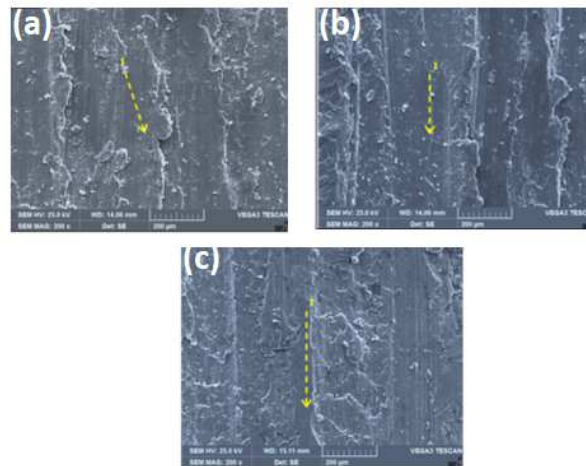
Composites	Friction Coefficient ( $\mu$ )				
	10N	20N	30N	40N	50N
Al 6026	0.45	0.46	0.47	0.46	0.46
Al 6026/3SiC	0.42	0.41	0.42	0.39	0.36
Al 6026/5SiC	0.42	0.41	0.42	0.38	0.35
Al 6026/7SiC	0.40	0.39	0.38	0.35	0.31
Al 6026/10SiC	0.38	0.37	0.36	0.30	0.26

The steady state friction coefficients (the mean values of  $\mu$  on last 450 m sliding distance) are summarized in Table 3 for different applied normal loads. It is seen that as the load increases from 10 to 30 N, the steady state  $\mu$  remains more or less constant for both the Al 6026 and Al-6026/SiC composites. However, at loads greater than 30 N,  $\mu$  decreases slowly for Al 6026 and Al-6026/SiC composites. Al 6026/10SiC has lower  $\mu$  values as compared with the corresponding values of unreinforced Al 6026 alloy under all applied normal loads.

### Examination of Worn Surface Morphology

The worn surfaces of the coupons corresponding to an applied load of 50 N were also investigated by SEM, as this is useful to understand the involved wear mechanisms. Figures 9(a)-(c) show the worn surfaces of coupons of Al 6026, Al 6026/5SiC and Al 6026/10SiC composites, respectively. Parallel depressions along the sliding direction (marked as yellow arrow in Figures 9(a)-(c) are visible on the damaged surface. It is obvious from the SEM micrographs that applied load has a pronounced effect on the morphology of Al 6026 and Al 6026/SiC composites.

In Figure 9(a), although grooves were observed that were mainly caused by abrasive wear, the ploughing was relatively severe as compared to Al 6026/5SiC and Al 6026/10SiC composites shown in Figures 9(b) and (c). The fine grooves become wider as well as deeper at an applied normal load of 50 N for Al 6026 (Figure 9(a)). Further, the worn surface show great surface damage, and more fragmentations were observed. In addition, the worn surface of Al 6026 is rough, network of micro cracks and debris formation can also be seen from the micrograph (Figure 9(a)).



**Figure 9: SEM Micrographs of: (a) Al 6026, (b) Al 6026/5SiC, (c) Al 6026/10SiC Composites.**

In case of Al 6026/SiC composites Figures 9(b) and (c) under the same test conditions, the characteristic features of the worn surfaces were clearly different in comparison with Al 6026. The micrographs displayed in Figures 9(b) and (c), the damaged surface indicated three fundamental highlights: (i) polished ceramic debris, (ii) matrix region around the ceramic debris, and (iii) bright debris particles sprinkled on the surface.

## CONCLUSIONS

Al 6026 alloy and SiC reinforced Al 6026 composites were tested for microstructure, hardness, mechanical properties and their dry sliding wear behaviour. Through the above analysis and comparisons of the test results, the following conclusions can be made.

- Comparing the properties of Al 6026/SiC with Al 6026, the hardness and tensile properties of composites increases with increase in SiC loading up to 7% and then slightly descents at 10 wt. %. This trend indicates that the optimum SiC reinforcement for the Al 6026 composite is about 7%.
- The Al 6026/SiC composites show better wear resistance at all weight percentages compared to Al 6026 under all wear test conditions.
- Generally, steady state friction coefficient values were found in all the composites and applied loads. The friction coefficients of Al 6026/SiC composites were lower than that of Al 6026 under all test conditions. For Al 6026/SiC composites, the friction coefficient is changing from 0.26 to 0.42.
- The wear mechanisms of Al 6026 alloy and Al 6026/SiC composites were adhesive and abrasive with fine grooves, less fragmentation, and smoother worn surfaces were noted for Al 6026/SiC composites.

## REFERENCES

1. Murty SN, Rao BN and Kashyap BP, (2003), *Compos Sci Technol* 63, 119–135.
2. Das DK, Mishra PC, Singh S and Pattanaik S, (2014), *Int J Mech Mater Eng* 9,1–15.
3. Tiryakioglu M and Campbell J, (2007), *Int J Cast Metals Res* 20, 25–29.
4. Clyne TW and Withers PJ, (1993), *An introduction to Metal Matrix Composites*. New York: Springer.

5. Miller WS, Zhuang L, Bottema J, Wittebrood AJ, Smet PD and Haszler A, (2000), *Mater Sci Eng A* 280,37–49
6. Brown KR, Venie MS and Woods RA, (1995) *J Minerals, Metals Mater Soci* 47:20–23
7. Laksmikanthan A, Bontha S, Krishna M, Koppad PG and Ramprabhu T, (2019) *J Alloys Compounds* 786, 570–580.
8. Hayrettin A, Tolga K, Ercan C and Huseyin C, (2006), *Tribol Int* 39, 213–220.
9. Yadav BN, Verma G, Muchhala D, Kumar R and Mondal DP, (2018), *Tribol Int* 128, 21–33.
10. Straffelini G, Bonollo F and Tiziani A, (1997), *Wear* 211,192–197.
11. Yadav, G. K. P., Reddy, M. V. V., & Prasad, P. R. *Fabrication and Structural Analysis of Aluminium Alloy (Lm25) Reinforced with Silicon Carbide and Graphite Particulate.*
12. How HC and Baker TN, (1997), *Wear* 210, 263–272.
13. Vanarotti M, Kori SA, Sridhar BR and Shrishail Padasalgi B, (2012), *Int Conf on Indust Technol Mgt* 11–15.
14. Muthu Kumar V, Venkatasamy R, Suresh Babu A, Jagan K and Nithin K, *Wear characteristic of Al alloy (LM4)-SiC particulate reinforced MMC, Int J of Prod Technol Mgt Res* 2011;2:49-54. (ISSN2229-3140)
15. Liang Y.N, Ma Z.Y, Li S.Z, Li S, Bi J, *Effect of particle size on wear behaviour of SiC particulate-reinforced aluminum alloy composites. J Mater Sci Lett* 1995; 14:114–116.
16. Niyas Salim, M. A., & Kumar, A. (2014). *Effect of Mg Enhancement in the Microstructure and Mechanical Properties of AC2A Aluminium Alloy. International Journal of Research in Engineering & Technology*, 2, 139–148.
17. Ramesh CS and Safiulla Mir, (2007), *Wear* 263, 29–635.
18. Ramesh CS, Keshavamurthy R, Channabasappa B.H and Ahmed Abrar, (2008), *Mater Sci Eng A* 502, 99–106.
19. *Aluminum Alloy 6026 - T9 Rod and Bar data sheet*, available at: [http://www.aalco.co.uk/datasheets/Aluminium-Alloy-6026-T9-Rod-and-Bar\\_143.ashx](http://www.aalco.co.uk/datasheets/Aluminium-Alloy-6026-T9-Rod-and-Bar_143.ashx), accessed: 20.08.2019.
20. M. Sreenivasa Reddy, Soma V. Chetty and Sudheer Premkumar, (2012), *Int J AdvEng Res* vol. 3, 1–7.
21. Sasimurugan T and Palanikumar K, (2011), *J Minerals Mater Character Eng* 10, 1213-1224.
22. Zuoyong Dou, GaohuiWu, Xiaoli Huang, Dongli Sun and Longtao Jiang, (2007), *Compos Part A* 38, 186–191.
23. Surappa MK and Rohatgi PK, (1981), *J Mater Sci* 16, 983–993.
24. Steel, W. B. O. F. C. *Effect of Thermo Mechanical Processing on Microstructure and Wear Behavior of Free-Carbide Steel Containing Different Aluminum.*
25. Saikeerthi SP, Vijayaramnath B and Elanchezhian C, (2014), *Int J Eng Res* 72, 44–48.
26. Chawla KK, (1997), *Composite materials: Science and Engineering*, 2<sup>nd</sup> edn. Press: Springer-Verlag, New York.
27. LloydDJ, (1994) *Int Mater Reviews* 39,1–23.
28. Al-Jafaari M, (2017) *Cryogenic treatment effect on fatigue behavior of 2024 and 7075 aluminum alloys with nano alumina composite material*[Ph.Dthesis].University of Technology.
29. Jarad, A. J., & Kadhim, Z. S. *Synthesis, Spectral, Dyeing Performance and Biological Activity Studies of Azo Dyes Complexes with Some Metal Ions.*
30. Kumar B and Menghani JV, (2016), *Int J Mater Eng Innov* 2016, 7:1–14.

31. Ramesh A, Prakash JN, Shiva Shankare Gowda AS and Appaiah Sonnappa, (2009), *J Min Mater Charact Eng* 8, 93–106.
32. Shorowordi KM, Haseeb ASMA and Celis JP, (2006), *Wear* 261, 634–641.
33. Mondal DP, Das S, Jha AK and Yegneswaran AH, (1998), *Wear* 223, 131–138.
34. Tyagi Rajnesh, (2005), *Wear* 259, 569–576.

## AUTHOR'S PROFILE



**Dr. H M Somashekar** is working as Assistant Professor in the department of Mechanical Engineering at Dr. Ambedkar Institute of Technology, Bengaluru. He passed out graduation from National Institute of Engineering, Mysore, Post Graduation from SJCE, Mysore and Doctorate from UVCE, Bengaluru. He has 16 International Publications to his credit. He is Life Member of Institute of Engineers, Life Member of Indian Society of Technical Education. He has experience of more than 17 years.



**Gowthama K** is working as Assistant Professor in the department of Mechanical Engineering at SJBIT Bengaluru. He has 02 international publications to his credit. He has experience of more than 14 years.



**Dr. Suresha B** is working as Professor in the department of Mechanical Engineering at The National Institute of Engineering, Mysore. He passed out graduation from Mysore University, Post Graduation from IIT Madras, and Doctorate from Anna University, Chennai. He has 80 International Publications, 11 National Journals to his credit. He has guided 5 students for their Doctorate Degrees and 5 students are in final stage. He is Life Member of Institute of Engineers, Life Member of Indian Society of Technical Education. He has experience of more than 31 years.